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BlackLight Power Technology
A New Hydrogen Energy Source with the Potential for Direct Conversion to Electricity

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1. Introduction

BlackLight Power, Inc. (the Company), a Delaware corporation based in its 53,000 sq. ft. headquarters in Cranbury, New Jersey, believes it has developed a new hydrogen chemical process that generates power, plasma (a hot ionized glowing gas), and a vast class of new compositions of matter. Specifically, the Company has designed and tested a new proprietary energy-producing chemical process. The Company has developed high-power density, high-temperature, hydrogen gas cells that produce intense light, power orders of magnitude greater than that of the combustion of hydrogen at high temperatures, and power densities equal to those of many electric power plants. The Company is focusing on cells for generating light and plasma for lighting applications and direct conversion to electricity, respectively.

The cells generate energy through a chemical process (BlackLight Process) which the Company believes causes the electrons of hydrogen atoms to drop to lower orbits thus releasing energy in excess of the energy required to start the process. The lower-energy atomic hydrogen product of the BlackLight Process reacts with an electron to form a hydride ion which further reacts with elements other than hydrogen to form novel compounds called hydrino hydride compounds (HHCs) which are proprietary to the Company. The Company is developing the vast class of proprietary chemical compounds formed via the BlackLight Process. Its technology has far-reaching applications in many industries.

The power may be in the form of a plasma, a hot ionized glowing gas. The plasma may be converted directly to electricity with high efficiency, thus, avoiding a heat engine such as a turbine. The Company is working on direct plasma to electricity conversion. The device may be linearly scaleable from the size of hand held units to large units which could replace large turbines.

There are many advantages of the technology. The energy balance permits the use of electrolysis of water to split water into its elemental constituents of hydrogen and oxygen as the source of hydrogen fuel using a small fraction of the output electricity. Additionally, pollution produced by fossil and nuclear fuels should be eliminated since no green house gases, air pollutants, or hazardous wastes are produced. As no fossil fuels are required, the projected commercial operating costs are much less than that of any known competing energy source.

The Company's process may start with water as the hydrogen source and convert it to HHCs; whereas, fuel cells typically require a hydrocarbon fuel and an expensive reformer to convert hydrocarbons to hydrogen and carbon dioxide. The Company's plasma to electric conversion technology with no reformer, no fuel cost, creation of a valuable chemical by-product rather than pollutants or green house gases such as carbon dioxide, and significantly lower capital costs and operating and maintenance (O&M) costs are anticipated to result in household units that are competitive with central power and significantly superior to competing microdistributed power technologies such as fuel cells.

2. The BlackLight Process

Based on physical laws of nature, Dr. Mills theory predicts that additional lower energy states are possible for the hydrogen atom, but are not normally achieved because transitions to these states are not directly associated with the emission of radiation. Thus, the ordinary hydrogen atom as well as lower-energy hydrogen atoms (termed hydrinos by Dr. Mills) are stable in isolation. Mills theory further predicts that hydrogen atoms can achieve these states by a radiationless energy transfer with a nearby atom, ion, or combination of ions (a catalyst) having the capability to absorb the energy required to effect the transition. Radiationless energy transfer is common. For example, it is the basis of the performance of the most common phosphor used in fluorescent lighting. Thus, the Company believes hydrogen atoms can be induced to collapse to a lower-energy state, with release of the net energy difference between states. Successive stages of collapse of the hydrogen atom are predicted, resulting in the release of energy in amounts many times greater than the energy released by the combustion of hydrogen. Since the combustion energy is equivalent to the energy required to liberate hydrogen from water, a process which takes water as a feed material and produces net energy is possible. The equivalent energy content of water would thus be several hundred to several thousand times that of crude oil, depending on the average number of stages of collapse.

The Company is the pioneer of technology based on the chemical process of releasing chemical energy from hydrogen called the "BlackLight Process". More specifically, energy is released as the electrons of hydrogen atoms are induced by a catalyst to transition to lower-

energy levels (i.e. drop to lower base orbits around each atom's nucleus) corresponding to fractional quantum numbers. The lower energy atomic hydrogen product is called "hydrino", and the hydrogen catalyst to form hydrino is called a "transition catalyst". As hydrogen atoms are normally found bound together as molecules, a hot dissociator is used to break hydrogen molecules into individual hydrogen atoms. A vaporized catalyst then causes the normal hydrogen atoms to transition to lower-energy states by allowing their electrons to fall to smaller radii around the nucleus with a release of energy that is intermediate between chemical and nuclear energies. The products are power, plasma, light, and novel HHCs.

The catalysts used and the BlackLight Process are the proprietary intellectual property of the Company. The theory, data, and analysis supporting the existence of this new form of energy have been made publicly available [1-22]. Also see the BlackLight Power web page: www.blacklightpower.com. Laboratory scale devices demonstrating means of extracting the energy have been operated at the Company and at independent laboratories. Results to date indicate that the process can eventually provide economically competitive products in a wide range of applications including lighting, thermal, and electric power generation. The Company's gas energy cells, even in prototype stage, are frequently operating at power densities and temperatures equivalent to those of many coal fired electric power plants and produce about 100 times the energy of the combustion of the hydrogen fuel. The plasma is permissive of a direct plasma to electricity conversion technology as well as the production of electricity by conventional heat engines. The Company currently believes that the scale-up of energy cells to commercial power generation level will require mainly the application of existing industry knowledge in catalysis and power engineering.

The lower-energy atomic hydrogen product of the BlackLight Process reacts with an electron to form a hydride ion which further reacts with elements other than hydrogen to form novel compounds which are proprietary to the Company. The Company is developing the vast class of proprietary chemical compounds formed via the BlackLight Process. Test results indicate that the properties of HHCs are rich in diversity due to their extraordinary binding energy (i.e. the energy required to remove an electron which determines the chemical reactivity and properties). This new class of matter may be comparable to carbon in terms of the possibilities of new compositions of matter. Carbon is a base element for many useful compounds ranging from diamonds, to synthetic fibers, to liquid gasoline, to pharmaceuticals. The Company believes hydrino hydride ions have the potential to be as useful as carbon as a base "element". The novel compositions of matter and associated technologies have far-reaching applications in many industries including the chemical, lighting, computer, defense, energy, battery, propellant, munitions, surface coatings, electronics, telecommunications, aerospace, and automotive industries. The Company is focusing on developing a high voltage

battery and silane materials based on the novel hydride chemical products. Many additional applications of the chemical compounds are possible.

2.1 Confirmation of the BlackLight Process

Based on the solution of a Schrödinger-type wave equation with a nonradiative boundary condition based on Maxwell's equations, Mills [1-22] predicts that atomic hydrogen may undergo a catalytic reaction with certain atomized elements or certain gaseous ions which singly or multiply ionize at integer multiples of the potential energy of atomic hydrogen, 27.2 eV. For example, cesium atoms ionize at an integer multiple of the potential energy of atomic hydrogen, $m \cdot 27.2\ eV$. The enthalpy of ionization of Cs to Cs^{2+} has a net enthalpy of reaction of 27.05135 eV, which is equivalent to $m = 1$ [23]. And, the reaction Ar^{+} to Ar^{2+} has a net enthalpy of reaction of 27.63 eV, which is equivalent to $m = 1$ [23]. In each case, the reaction involves a nonradiative energy transfer to form a hydrogen atom that is lower in energy than unreacted atomic hydrogen. The product hydrogen atom has an energy state that corresponds to a fractional principal quantum number. Recent analysis of mobility and spectroscopy data of individual electrons in liquid helium show direct experimental confirmation that electrons may have fractional principal quantum energy levels [5]. The lower-energy hydrogen atom is a highly reactive intermediate which further reacts to form a novel hydride ion. Emission was observed from a continuum state of Cs^{2+} and Ar^{2+} at 53.3 nm and 45.6 nm, respectively [7]. The single emission feature with the absence of the other corresponding Rydberg series of lines from these species confirmed the resonant nonradiative energy transfer of 27.2 eV from atomic hydrogen to atomic cesium or Ar^{+}. The catalysis product, a lower-energy hydrogen atom, was predicted to be a highly reactive intermediate which further reacts to form a novel hydride ion. The predicted hydride ion of hydrogen catalysis by either cesium atom or Ar^{+} catalyst is the hydride ion $H^{-}(1/2)$. This ion was observed spectroscopically at 407 nm corresponding to its predicted binding energy of 3.05 eV [7].

Typically, the emission of extreme ultraviolet (EUV) light from hydrogen gas is achieved by a discharge at high voltage, a high power inductively coupled plasma, or in hot fusion research, a plasma is created and heated by radio waves to 10s of millions of degrees with confinement of the hot plasma by a toroidal (donut shaped) magnetic field. The Company has observed intense EUV emission at low temperatures (e.g. $\approx 10^{3}\ K$) from atomic hydrogen and certain atomized elements or certain gaseous ions [7, 9-15] that served as catalysts. The Company has tested over 130 elements and compounds which covers essentially all of the elements of the periodic chart. The chemical interaction of catalysts with atomic hydrogen at

temperatures below 1000 K has shown surprising results in terms of the emission of the Lyman and Balmer lines [7, 9-15] (atomic hydrogen emission ten times more energetic than the combustion of hydrogen), emission of lines corresponding to lower-energy hydrogen states and the corresponding hydride ions, and the formation of novel chemical compounds [16-22].

Over 20 independent labs have performed 25 types of analytical experiments that confirm the Company's novel catalytic reaction of atomic hydrogen which produces an anomalous discharge or plasma and produces novel hydride compounds [7-22]. Experiments that confirm the novel hydrogen chemistry include extreme ultraviolet (EUV) spectroscopy [7, 9-12, 15], plasma formation [7-15], power generation [8-10, 15, 22], and analysis of chemical compounds [16-22]. For example:

1.) Pennsylvania State University, Chemical Engineering Department has determined heat production associated with hydrino formation with a Calvet calorimeter that showed the generation of $10^7\ J/mole$ of hydrogen, as compared to $2.5\,X\,10^5\ J/mole$ of hydrogen anticipated for standard hydrogen combustion [24]. Thus, the total heats generated appear to be 100 times too large to be explained by conventional chemistry, but the results are completely consistent with Mills model.

2.) Lines observed at the Institut Fur Niedertemperatur-Plasmaphysik e.V. by EUV spectroscopy could be assigned to transitions of atomic hydrogen to lower energy levels corresponding to lower energy hydrogen atoms and the emission from the excitation of the corresponding hydride ions [12]. For example, the product of the catalysis of atomic hydrogen with potassium metal, $H\left[\frac{a_H}{4}\right]$ may serve as both a catalyst and a reactant to form $H\left[\frac{a_H}{3}\right]$ and $H\left[\frac{a_H}{6}\right]$. The transition of $H\left[\frac{a_H}{4}\right]$ to $H\left[\frac{a_H}{6}\right]$ induced by a multipole resonance transfer of $54.4\ eV$ $(2 \cdot 27.2\ eV)$ and a transfer of $40.8\ eV$ with a resonance state of $H\left[\frac{a_H}{3}\right]$ excited in $H\left[\frac{a_H}{4}\right]$ is represented by $H\left[\frac{a_H}{4}\right] + H\left[\frac{a_H}{4}\right] \rightarrow H\left[\frac{a_H}{6}\right] + H\left[\frac{a_H}{3}\right] + 176.8\ eV$. The predicted $176.8\ eV$ (70.2 Å) photon is a close match with the observed 73.0 Å line. The energy of this line emission corresponds to an equivalent temperature of 1,000,000 °C and an energy over 100 times the energy of combustion of hydrogen.

3.) Transitions of atomic hydrogen to lower energy levels corresponding to lower energy hydrogen atoms has been identified in the extreme ultraviolet emission spectrum from interstellar medium [4].

4.) Observation of intense extreme ultraviolet (EUV) emission has been reported at low temperatures (e.g. $\approx 10^3\ K$) from atomic hydrogen and certain atomized elements or certain

gaseous ions [7, 9-15]. The only pure elements that were observed to emit EUV were those wherein the ionization of t electrons from an atom to a continuum energy level is such that the sum of the ionization energies of the t electrons is approximately $m \cdot 27.2\ eV$ where t and m are each an integer. Potassium, cesium, and strontium atoms and Rb^+ ion ionize at integer multiples of the potential energy of atomic hydrogen and caused emission. Whereas, the chemically similar atoms, sodium, magnesium and barium, do not ionize at integer multiples of the potential energy of atomic hydrogen and caused no emission. A catalyst may also be provided by the transfer of t electrons between participating ions. The transfer of t electrons from one ion to another ion provides a net enthalpy of reaction whereby the sum of the ionization energy of the electron donating ion minus the ionization energy of the electron accepting ion equals approximately $m \cdot 27.2\ eV$ where t and m are each an integer. Potassium ions can also provide a net enthalpy of a multiple of that of the potential energy of the hydrogen atom. The second ionization energy of potassium is $31.63\ eV$; and K^+ releases $4.34\ eV$ when it is reduced to K [23]. The combination of reactions K^+ to K^{2+} and K^+ to K, then, has a net enthalpy of reaction of $27.28\ eV$, which is equivalent to $1 \cdot 27.2\ eV$. Observation of intense extreme ultraviolet (EUV) emission has been reported at low temperatures (e.g. $\approx 10^3\ K$) from K_2CO_3; whereas, chemically similar Na_2CO_3 caused no emission [11].

5.) An energetic plasma in hydrogen was generated using strontium atoms as the catalyst. The plasma formed at 1% of the theoretical or prior known voltage requirement with 4,000-7,000 times less power input power compared to noncatalyst controls, sodium, magnesium, or barium atoms, wherein the plasma reaction was controlled with a weak electric field [10, 15]. The light output for power input increased to 8600 times that of the control when argon was added to the hydrogen strontium plasma to form Ar^+ catalyst [9].

6.) The optically measured output power of gas cells for power supplied to the glow discharge increased by over two orders of magnitude depending on the presence of less than 1% partial pressure of certain catalysts in hydrogen gas or argon-hydrogen gas mixtures [8].

7.) In experiments performed at the Institut Fur Niedertemperatur-Plasmaphysik e.V., an anomalous plasma formed with hydrogen-potassium mixtures wherein the plasma decayed with a two second half-life which was the thermal decay time of the filament which dissociated molecular hydrogen to atomic hydrogen when the electric field was set to zero [13]. This experiment showed that hydrogen line emission was occurring even though the voltage between the heater wires was set to and measured to be zero and indicated that the emission was due to a reaction of potassium catalyst with atomic hydrogen which confirms a new chemical source of power.

8.) A plasma of hydrogen and certain alkali ions formed at low temperatures (e.g. $\approx 10^3\ K$) as recorded via EUV spectroscopy and the hydrogen Balmer and alkali line emissions

in the visible range. The observed plasma formed at low temperatures (e.g. $\approx 10^3\ K$) from atomic hydrogen generated at a tungsten filament that heated a titanium dissociator and a catalyst comprising one of potassium, rubidium, cesium, and their carbonates and nitrates. These atoms and ions ionize to provide a catalyst with a net enthalpy of reaction of an integer multiple of the potential energy of atomic hydrogen ($m \cdot 27.2\ eV,\quad m =$ integer) to within 0.17 eV and comprise only a single ionization in the case of a potassium or rubidium ion. Whereas, the chemically similar atoms of sodium and sodium and lithium carbonates and nitrates which do not ionize with these constraints caused no emission. To test the electric dependence of the emission, a weak electric field of about 1 V/cm was set and measured to be zero in $< 0.5\ X\ 10^{-6}$ sec. An anomalous afterglow duration of about one to two seconds was recorded in the case of potassium, rubidium, cesium, K_2CO_3, $RbNO_3$, and $CsNO_3$. Hydrogen line or alkali line emission was occurring even though the voltage between the heater wires was set to and measured to be zero. These atoms and ions ionize to provide a catalyst with a net enthalpy of reaction of an integer multiple of the potential energy of atomic hydrogen to within less than the thermal energies at $\approx 10^3\ K$ and comprise only a single ionization in the case of a potassium or rubidium ion. Since the thermal decay time of the filament for dissociation of molecular hydrogen to atomic hydrogen was similar to the anomalous plasma afterglow duration, the emission was determined to be due to a reaction of atomic hydrogen with a catalyst that did not require the presence of an electric field to be functional.

9.) The formation of novel compounds provide substantial evidence supporting a novel reaction of hydrogen as the mechanism of the observed EUV emission and anomalous discharge. Novel hydrogen compounds have been isolated as products of the reaction of atomic hydrogen with atoms and ions identified as catalysts in the reported EUV studies [7-22]. Novel inorganic alkali and alkaline earth hydrides of the formula MH^* and MH^*X wherein M is the metal, X, is a singly negatively charged anion, and H^* comprises a novel high binding energy hydride ion were synthesized in a high temperature gas cell by reaction of atomic hydrogen with a catalyst such as potassium metal and MH, MX or MX_2 corresponding to an alkali metal or alkaline earth metal compound, respectively [16-17, 19]. Novel hydride compounds were identified by 1.) time of flight secondary ion mass spectroscopy which showed a dominant hydride ion in the negative ion spectrum, 2.) X-ray photoelectron spectroscopy which showed novel hydride peaks and significant shifts of the core levels of the primary elements bound to the novel hydride ions, 3.) ^1H nuclear magnetic resonance spectroscopy (NMR) which showed extraordinary upfield chemical shifts compared to the NMR of the corresponding ordinary hydrides, and 4.) thermal decomposition with analysis by gas chromatography, and mass spectroscopy which identified the compounds as hydrides [17, 19].

An upfield shifted ^{1}H NMR peak is consistent with a hydride ion with a smaller radius as compared with ordinary hydride since a smaller radius increases the shielding or diamagnetism. Thus, the NMR shows that the hydride formed in the catalytic reaction has been reduced in distance to the nucleus indicating that the electrons are in a lower-energy state. Compared to the shift of known corresponding hydrides the NMR provides direct evidence of reduced energy state hydride ions.

The NMR results confirm the identification of novel hydride compounds $MH*X$, $MH*$, and MH_2^* wherein M is the metal, X, is a halide, and $H*$ comprises a novel high binding energy hydride ion. For example, large distinct upfield resonances were observed at -4.6 ppm and -2.8 ppm in the case of $KH*Cl$ and $KH*$, respectively. Whereas, the resonances for the ordinary hydride ion of KH were observed at 0.8 and 1.1 ppm. The presence of a halide in each compound $MH*X$ does not explain the upfield shifted NMR peak since the same NMR spectrum was observed for an equimolar mixture of the pure hydride and the corresponding alkali halide (MH/MX) as was observed for the pure hydride, MH. The synthesis of novel hydrides such as $KH*$ with upfield shifted peaks prove that the hydride ion is different from the hydride ion of the corresponding known compound of the same composition. The reproducibility of the syntheses and the results from five independent laboratories confirm the formation of novel hydride ions [16].

3. Business Units

The Company believes that it has created a commercially competitive new source of energy, a new source of plasma which releases rather than consumes energy, a new source of light, and a revolutionary new field of hydrogen chemistry. With its achievements of a sustained 100,000+ °C plasma of hydrogen with essentially no power input to its power cell and synthesis of over 40 novel compounds in bulk with extraordinary properties the Company is focusing on product development. Initial target products are a direct plasma to electric power cell targeted at the residential and commercial microdistributed markets and the premium power market. Additional market objectives for the plasma and chemistry technologies are lighting sources, a high voltage battery to power portable electronics and electric vehicles, and chemical products and processes based on silicon and hydrino chemistry.

The Company has two basic business units—power and chemical. The plasma-electric technology may represent a near-term huge energy market. But, in the case of a large central power plant, the Company estimates that the potential revenues from the chemicals produced with power generation may eclipse the electricity sales. However, both offer extraordinary

potential revenue and profit. Since enormous power (easily convertible to electricity) is a product of the BlackLight Process, the two units can operate in tandem seamlessly.

The priorities of the Company's power business is the residential and commercial microdistributed markets and the premium power market based on its plasma-electric power cell technology. The time to market should be near term for these relatively small-scale, simple devices that are projected to be inexpensive to manufacture, service, and use, and vastly superior to competing technologies such as internal combustion engine gensets, fuel cells, and microturbines. Selected statistics on electric generation are given in Table 1.

Table 1. Statistics on electric generation.

US Electric Market
- $217 billion in annual US sales (1998).
- 43% Residential
- 32% Commercial
- 22% Industrial
- 5% Other

Capital Expenditures Required to Meet New Generation Demand
- Estimated at $90 Billion Globally with 10% in US in 1999
- $21 Billion will be spent on Premium Power in 2000
- $30 Billion in 2002
- $50 Billion in 2005

Premium Power Consumption/Demand
- Estimated to be 30,000 MW in 1999
- Estimated to be 500,000 MW in 2000
- Double digit growth expected over next five years

Early adopters of BlackLight power systems are expected to be those that require premium power generated on-site. The premium power market* includes businesses where brief electrical outages can cause severe monetary loss: telecommunication sites, computer centers, server hotels, e-commerce centers, semiconductor fabrication facilities, and others. The market size was estimated to be 30,000 MW in 1999 and growth to be multiples of the

* The premium power market is also known as the 9's market and the powercosm market. Utility grids provide 99.9% reliability, or 8 hours of disruption per year. For the Internet economy, even small fractions of a second can cost millions of dollars. In high technology manufacturing industries, even hours of disruption can shut down operations for days, again costing millions. More reliability is measured in %, the more 9's required (99.999...%), the smaller the fractions of a second power is disrupted and the more valuable the power.

entire energy market rate [25-26]. The Glider Group and Stephens Inc. estimates [27-28] that this market is 15% of the current US energy market, and it will be 30—50% within 3—5 years as the internet economy build-out continues. This market is characterized by early adoption of emerging technologies and an insensitivity to cost. For example, a typical rate is over $1,000 per kWh, and the rate for the upper-end of the reliability scale, six 9's reliable power, is about $1 million per kWh compared to 5 ¢ per kWh for three 9's power supplied by the grid. The premium power market is a multi-billion dollar market. The current equipment market is $21 billion in hardware alone and is projected to eclipse the profitability of the entire utility market in the near term [29].

Table 2. Competitive Advantages of The BlackLight Power Process.

Cost Per KWH of Alternative Energy Sources	
Coal	4-5 ¢
Natural Gas	4-5 ¢
Oil	4-5 ¢
Nuclear Power	5-6 ¢
Hydroelectric	4-7 ¢
Geothermal	5-8 ¢
Wind	5-9 ¢
Solar	10-12 ¢
Photovoltaic	30-40 ¢
BlackLight *	<1 ¢

*Cost figures include operating, maintenance, capital generating expense of plasma-electric system (Source: EPRI, BlackLight Power, Inc.)

BlackLight's Energy Systems design advantages are: virtually instantaneous turn on/off, simplicity, easy logistics, low capital cost, low operational and maintenance cost, easy redundancy (for reliability), and no pollution. With our current design, BlackLight projects capital costs around $25—100 per kW, and very low generation cost (<$0.01 per kWh). This is lower than competitive solutions, but in this market segment cost is not a driver. Our chief competitors are reciprocating engine-based gensets built by Catapillar, Cummins, and others. Additional competition might be from newer entrants: microturbines and fuel cells. The former competitors, fossil-fueled engines, have an advantage because they are an incumbent technology, but 1.) they will not be able to significantly improve their reliability, 2.) they have a short lifetime, 3.) they do not meet pollution requirements, and 4.) they can not reduce their O&M costs to be competitive with our solution. The latter competitors have a slight advantage

in name recognition relative to BlackLight, but microturbines and fuel cells are not suited for the premium power market. Fuel cells and turbine systems take too long to start up, and are difficult to harmonize with grid-supplied power. Thus, they are ineffective at improving power reliability.

Due to superior performance of its technology, the Company expects early adoption by the premium power market with expansion into the broader microdistributed market. The broader market which includes hundreds of millions of homes and businesses in the US and Europe will be drawn by significant cost savings and increasing unreliability of the grid with a lack of viable microdistributed alternatives. The populace of the third world, particularly Asia, represents a further enormous market opportunity for which BlackLight technology is particularly suited, since in addition to very low capital and O&M costs, no fuel or electrical grid infrastructure is required.

In terms of its development strategy for large scale systems, the Company has decided to focus on developing the chemical business unit as a first priority over large power plants. In addition to the possibility of larger revenue, the chemical business offers several other initial advantages. A power generation plant based on thermal energy would have to be scaled-up while maintaining current or higher levels of power density before it could be commercialized. Scaling up to a power plant of very large proportions has engineering risks. While there are engineering risks associated with the scale-up for chemical production, they are not as daunting. Some potential product areas such as electronics are projected to have very high value in small quantity. Moreover, in terms of gaining widespread scientific and commercial acceptance for the BlackLight Process, it is relatively easy to validate the properties of a chemical compound. A solid chemical compound is a product that can be examined directly and its existence proven unequivocally—it either exists or it doesn't. This also means that its patents are well defined and easy to defend. The products are much more diverse, so broad industry adoption is anticipated.

In addition to direct cell power to electric power conversion, thermal power from the plasma produced by the BlackLight Process may be converted to electricity by powering a turbine. Contemporary central station thermal generation systems have been optimized to match their respective thermal sources. Since BlackLight-technology is not combustion or nuclear, an opportunity exists to dramatically reduce the complexity of the generation station. The BlackLight Process may be used as a thermal source for central or distributed power through use of a modified steam or gas turbine. The BlackLight adaptation of the steam-based system replaces the heat source of the boiler with a BlackLight gas cell. The BlackLight adaptation of the gas turbine replaces the combustor of a conventional machine with a gas cell and a heat exchanger incorporating the BlackLight Process. High pressure air from the

compressor is heated by the BlackLight energy cell heat exchanger before expanding through the power turbine. The exhaust would contain no combustion products. With energy production from hydrogen at a hundred times combustion energy, fuel cost would become an inconsequential consideration, and refueling intervals would be consistent with other maintenance. Alternatively, an on-site electrolysis system producing hydrogen from water could provide unlimited fuel with periodic additions of small quantities of water.

A typical chemical plant is projected to produce 100 MW electric power as a side product. Power and chemical cells may be fabricated using readily available materials, and systems such as steam or gas turbine systems are scalable over a large range [e.g. distributed units (1 MW) to central power plants (1 GW)]. The projected cost for a combined chemical and energy plant is about $250/kW. The two functions could work seamlessly together and generate a dual income stream with a reduction of business risk. Rather than producing nuclear or fossil fuel waste which requires disposal, the BlackLight chemical plant will produce HHCs which have potential for far-reaching applications in many industries such as batteries for electric vehicles at significant earnings. For example, a 100 MW chemical plant is projected to produce $300 M in electric vehicle battery revenue from 200,000 batteries with $23 M from electricity sales at 3 ¢ kWh.

4. Solution to the Energy Problem?

The world's current energy system is unsustainable. Furthermore, the world's current energy system is not sufficiently reliable or affordable to support widespread economic growth. The productivity of one-third of the world's people is compromised by lack of access to commercial energy, and perhaps another third suffer economic hardships and insecurity due to unreliable energy supplies [30]. Solar and wind power are prohibitively expensive. Billions of dollars have been spent to harness the energy of hydrogen through hot fusion using extremely hot plasmas created with enormous energy input using complex, expensive systems. By contrast, the Company's reactions indicate that over 100 times the energy of its combustion is released from hydrogen with the formation of a plasma as a by-product at relatively low temperatures with simple, inexpensive systems. And, in the Company's power cells, the plasma may be converted directly to electricity with high efficiency avoiding a heat engine such as a turbine. In addition, rather than producing radioactive waste, the BlackLight Process produces compounds having extraordinary properties. The implications are that a vast new energy source and a new field of hydrogen chemistry have been discovered.

The advantages of the BlackLight process over existing energy forms, such as fossil fuels and nuclear power, include: (1) the water, which is the fuel for the process, is safe and

inexpensive to contain; (2) the reaction is prospectively easily controlled; and (3) the byproduct, HHCs, have great potential commercial value. The projection of the capital cost per kilowatt capacity of BlackLight's system may be an order of magnitude less than that of the typical capital cost for a fossil fuel system and two orders of magnitude less than that of the typical capital cost for a nuclear system. The power cell may also be interfaced with conventional steam-cycle or gas turbine equipment used in fossil fuel power plants. In either case, fuel costs are eliminated since the fuel, hydrogen, can be generated by a fraction of the electrical output power. The cost factors per kilowatt/hour are the capital, maintenance and operation costs of the gas cell and plant. These costs are further reduced by elimination of the costs of handling fossil fuels and managing the pollution of air, water, and ground caused by the ash generated by fossil fuels.

4.1. BlackLight Distributed Generation

Central station generation and distribution, the mainstay of electrical power production for the last 100 years worldwide, is now being supplemented in an increasing number of areas by smaller power units closer to the end-user group. Most distributed-generation units are in the capacity range of 100 kW—3 MW (electric), but some could be as large as 250 MW (electric). Distributed generation solves some of centralized power's inherent problems of transmission and distribution line losses, electromagnetic pollution fears from high-tension lines, cost and difficulty of transmission-line maintenance, and inefficiencies in load factor design of power plants (wherein the use of a 20% capacity safety factor is still a common industry practice when estimating peak loading). The Company's technology may be ideal for distributed generation with significant reductions in grid complexity and generation capital equipment requirements.

The Company projects that the residential market may be broadly served by a 25 kW unit, and the commercial market may be broadly served by modular 1 MW units. This approach may replace the grid since in addition to avoidance of line losses, a major economic advantage of distributed power is the avoidance of transmission tariffs which could amount to 50% of the cost of electricity to a customer. Using BlackLight's distributed power generation technology, considerable savings can be realized by eliminating the transmission and distribution capital equipment, operations, and maintenance costs. Also, energy can be saved, given that electricity "demand" also includes substantial transmission and distribution losses from the traditional central-station type power generation systems. These considerations are important considerations for developing nations.

As the world's population grows from about 6 billion (in 1999) to an estimated 7 billion by 2010, most of the new energy demand will come from less-developed countries (LDCs), as these countries' living standards increase. LDC energy demand has long been answered by economic development programs generally aimed at the development of large, central-station power plants. These do not adequately address the thermal and lighting needs of half the world's population which is poor, many of whom still use carbon fuels for these purposes. The solution for LDC's may be distributed power facilitated by BlackLight Power technology since no fuel, power plant, or transmission grid infrastructure is required.

5. BlackLight Power Technology—A New Paradigm in Energy and Electricity Generation

The products of the BlackLight Process are power, plasma, light, and novel HHCs. Using advanced catalysts in its gas power cell, the Company has sustained an energetic plasma in hydrogen at 1% of the theoretical or prior-known voltage requirement and with 1000's of times less power input in a system wherein the plasma reaction is controlled with a weak electric field. A plasma is a very hot, glowing, ionized gas. The plasma is produced from reactions which release energies over 100 times the energy of the combustion of hydrogen and correspond to an equivalent electron temperature of over 1,000,000 °C. The plasma produced in the Company's cells cannot be produced by any chemical reaction other than the Company's process.

5.1. Plasma-Electric Power Converter

Typically, a heat engine such as a turbine is used for converting heat into electricity. However, plasma power may be directly converted into electrical power. The technology is not based on heat. Thus, heat sinks such as a river or cooling towers as well as thermal pollution are largely eliminated. Based on research and development in this area of converters, the Company expects that routine engineering will result in devices that have higher conversion efficiencies than turbines. The device may be linearly scaleable from the size of hand held units to large units which could replace large turbines. And, unlike turbine technology wherein the cost per unit capacity soars with miniaturization, the Company anticipates that the unit cost per capacity will be insensitive to scale. The Company anticipates applications for its technology in broad markets such as premium power, microdistributed power, motive power, consumer electronics, portable electronics, telecommunications, aerospace, and uninterruptable, remote, and satellite power supplies.

Plasma may be directly converted into electricity using a direct converter. Several examples being studied and tested by BlackLight are microwave devices such as a gyrotron, a magnetic mirror magnetohydrodynamic power converter, a charge drift direct power converter, and a Post or Venetian blind direct power converter.

5.1.1. Gyrotron Converter

A gyrotron is an established technology for converting energetic electrons into microwaves. Conventionally the source of energetic electrons comprises an electron beam or a plasma formed by electrical input such as a high voltage discharge. Prior to the development of the Company's technology, it was not possible to generate a plasma in hydrogen chemically. The BlackLight Process generates an energetic plasma in hydrogen which is *a new source of energy*.

The energy released by the catalysis of hydrogen to form HHCs produces a plasma in the cell. The energetic electrons of the plasma produced by the BlackLight Process are introduced into an axial magnetic field where they undergo cyclotron motion. The force on a charged ion in a magnetic field is perpendicular to both its velocity and the direction of the applied magnetic field. The electrons of the plasma orbit in a circular path in a plane transverse to the applied magnetic field for sufficient field strength at an ion cyclotron frequency ω_c that is independent of the electron velocity. Thus, a typical case which involves a large number of electrons with a distribution of velocities will be characterized by a unique cyclotron frequency that is only dependent on the electron charge to mass ratio and the strength of the applied magnetic field. There is no dependence on their velocities. The velocity distribution will, however, be reflected by a distribution of orbital radii. The electrons emit electromagnetic radiation with a maximum intensity at the cyclotron frequency. The velocity and radius of each electron may decrease due to loss of energy and a decrease of the temperature.

The gyrotron comprises a resonator cavity which has a dominant resonator mode at the cyclotron frequency. The plasma contains electrons with a range of energies and trajectories (momenta) and randomly distributed phases initially. Electromagnetic oscillations are generated from the electrons to produce induced radiation due to the grouping of electrons under the action of the self-consistent field produced by the electrons themselves with coherent radiation of the resulting packets. In this case, the device is a feedback oscillator. The theory of induced radiation of excited classical oscillators such as electrons under the action of an external field and its use in high-frequency electronics is described by A. Gaponov et al. [31]. The electromagnetic radiation emitted from the electrons excites the mode of the cavity and is received by a resonant receiving antenna.

The engineering of the BlackLight gyrotron converter is based on established microwave technology which may achieve very high conversion efficiencies (e.g. 80%) of energetic electrons into microwaves [32]. A 0.1 Tesla magnetic field will produce about 2.5 GHz microwaves. The microwaves are then rectified into DC electricity. Rectification efficiency at 2.5 GHz is about 95% [33-36]. The DC electricity may be inverted and transformed into any desired voltage and frequency with conventional power conditioning equipment.

5.1.2. Magnetic Mirror Magnetohydrodynamic (Mirror-MHD) Power Converter

The BlackLight plasma comprises energetic electrons and ions which may be converted into a directional flow using a magnetic mirror described by Jackson [37] and directly converted into electricity. A magnetic mirror has a magnetic field gradient in a desired direction of ion flow (e.g. z-axis) where the initial parallel velocity of plasma electrons $v_{\parallel 0}$ increases as the orbital velocity $v_\perp$ decreases with conservation of energy according to the adiabatic invariant $\frac{v_\perp^2}{B} = \text{constant}$, the linear energy being drawn from that of orbital motion. As the magnetic flux **B** decreases the radius a will increase such that the flux $\pi a^2 B$ remains constant. The adiabatic invariance of flux through the orbit of an ion is a means to form a flow of ions along the z-axis with the conversion of $v_\perp$ to $v_\parallel$ such that $v_\parallel > v_\perp$.

The plasma is generated selectively in a desired region of the BlackLight power cell. A magnetic mirror of a magnetic mirror magnetohydrodynamic power converter is located in the desired region such that electrons and ions are forced from a homogeneous distribution of velocities in x, y, and z to a preferential velocity along the axis of magnetic field gradient of the magnetic mirror, the z-axis. The mirror-MHD power converter further comprises a magnetohydrodynamic power converter comprising a source of magnetic flux transverse to the z-axis. Thus, the ions have a preferential velocity along the z-axis and propagate into the region of the transverse magnetic flux from the source of transverse flux. The Lorentzian force on the propagating electrons and ions with charge e is given by $F = e\mathbf{v} \times \mathbf{B}$. The force is transverse to the ion velocity and the magnetic field and in opposite directions for positive and negative ions. Thus, charge separation occurs for electrons and positive ions. The magnetohydrodynamic power converter further comprises at least two electrodes which may be transverse to the magnetic field to receive the transversely Lorentzian deflected ions which creates a voltage across the electrodes. The Lorentzian deflector or magnetohydrodymanic generator may be a segmented Faraday generator as described by Petrick [38]. The voltage may drive a current through an electrical load.

According to the adiabatic invariant $\frac{v_\perp^2}{B} = \text{constant}$, the parallel velocity at any position along the z-axis is given by $v_{\|0}^2 = v_0^2 - v_{\perp 0}^2 \frac{B(z)}{B_0}$ where the zero subscript represents the original condition. In the case that $v_{\|0}^2 = v_{\perp 0}^2 = 0.5 v_0^2$ and $\frac{B(z)}{B_0} = 0.1$ at the magnetohydrodymanic power converter, the velocity is 95% parallel to the z-axis. The deflection of the ions may be essentially 100%. Thus, very high efficiency may be achieved. Furthermore, very high power may be achieved since very large currents are possible for a given ion energy corresponding to a maximum electrode voltage, and series magnetohydrodymanic power converters may achieve high voltages.

5.1.3. Charge Drift Direct Power Converter

The charge drift direct power converter described by Timofeev and Glagolev [39-40] comprises a magnetic field gradient in a direction transverse to the direction of a source of a magnetic flux **B** and a source of magnetic flux **B** having a curvature of the field lines. Jackson [41] shows that if charged particles move through regions where a magnetic field gradient exists in a direction transverse to the direction of a magnetic flux **B** or the magnetic field has curvature in a plane, drifting negatively and positively charged ions move in opposite directions perpendicular to the plane formed by **B** and the direction of the magnetic field gradient or the plane in which **B** has curvature. Jackson [42] also shows that the motion of a charged particle in crossed electric and magnetic fields with the electric field **E** less that the magnetic field **B** is gyration around the magnetic field with a uniform drift at velocity **u** in the direction perpendicular to both the perpendicular electric and magnetic fields.

A flow of ions from a BlackLight cell may be received at a plasma injection port of the charge drift power converter, or the plasma generating reaction may be within the converter. In both the case of the gradient field and the curved field, the thermal energy of the plasma is converted into electrical energy as the charged particles drift in crossed fields: an inhomogeneous magnetic field and an electric field perpendicular to the magnetic field. The ions move across the gradient or curved field due to the $\mathbf{E} \times \mathbf{B}$ drift velocity affected by the crossed fields [42]. The drifting negatively and positively charged ions move in opposite directions perpendicular to plane formed by **B** and the direction of the magnetic field gradient or the plane in which **B** has curvature. In each case, the separated ions generate a voltage at opposing capacitors that are parallel to the plane with a concomitant decrease of the thermal energy of the ions. The generated voltage has a corresponding electric field which is

perpendicular to the magnetic flux **B** having a perpendicular gradient or curvature. Thus, the energy is converted in crossed imposed magnetic and resultant electric fields. The magnetic flux **B** perpendicular to the electric field prevents the charges from flowing along the electric field and canceling it.

High conversion efficiencies are possible. In the case that the magnetic field decreases by a factor of three across the transverse gradient, and the initial kinetic energy is primarily in the parallel direction, the efficiency may be 90% [39-40].

5.1.4. Post or Venetian Blind Direct Power Converter

A Post or Venetian blind direct power converter described by Moir and Freis [43-44] comprises a magnetic mirror which is a source of a directional flow of ions from the BlackLight power cell as described for the mirror-MHD case. The Post converter further comprises an electrostatic collector which deflects electrons at a first set of negatively biased electrodes, then stops the positive ions at a series of positively biased electrodes to convert the axial kinetic energy into electrical energy. High efficiencies (e.g. 86 %) have been achieved [43].

In the plasma formed by the BlackLight Process, the electrons have greater energy than the positive ions. Thus, in the application of a Post direct converter to the BlackLight plasma, the positive ions are separated from the electrons at a first set of electrodes, and the energetic electrons are stopped at a second set of electrodes as the primary source of power conversion.

The power produced by the BlackLight Process and the converted power may be matched such that a steady state of power production and power flow from the cell may be achieved. The rate of the hydrogen catalysis reaction may be controlled by controlling the total pressure, the atomic hydrogen pressure, the catalyst pressure, the particular catalyst, and the cell temperature. Very fast response times may be achieved by controlling the rate of reaction and plasma formation with an applied electric or magnetic field which influences the catalysis rate. Plasma and a direct converter can respond essentially instantaneously. Thus, unprecedented load following capability is possible.

The plasma formed by the BlackLight Process shown in Figure 1 and a direct energy converter test-bed shown in Figure 2 have been tested independently. Current work is in progress on selecting the most commercially competitive option for converting the BlackLight Process generated plasma into electricity.

Figure 1. Plasma Generated by the BlackLight Process.

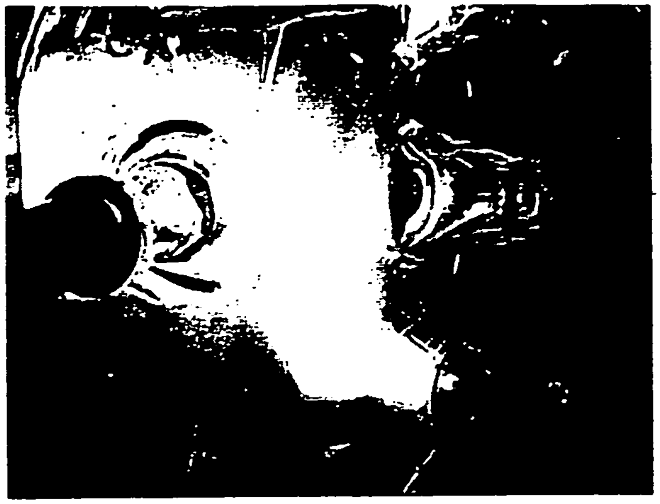

Figure 2. Direct Plasma-Electric Converter Test-bed.

5.2. Power Balance Analysis

The commercial unit would comprise a 3-stage power generator. Stage 1 would be electrolysis to provide hydrogen fuel; stage 2—production of plasma in a gas cell; and stage 3—conversion of plasma to electricity.

Using even relatively conservative assumptions for reaction yield and power density, a competitive power generation unit appears easily possible: (1) Production of about 100 times electrical power as electrolysis power; (2) Production of green emission (oxygen only) zero CO_2 emission; (3) No fossil-fuel combustion by-products; (4) Essentially no waste heat since the direct converter is not a heat engine; (5) Tremendously more efficient at energy conversion to electricity; and (5) Projected to dominate the home and microdistributed markets.

5.3. Comparison with Competing Microdistributed Technologies

The Company's process may start with water as the hydrogen source and convert it to HHCs; whereas, fuel cells typically require a hydrocarbon fuel and an expensive reformer to convert hydrocarbons to hydrogen and carbon dioxide. The Company's plasma to electric conversion technology with no reformer, no fuel cost, creation of a valuable chemical by-product, and significantly lower capital costs and O&M costs are anticipated to result in household units that are competitive with central power and significantly superior to competing microdistributed power technology such as fuel cells and micro combustion turbines. With a focus on large scale production of microdistributed devices, the Company anticipates rapid penetration of the electricity energy market. In this case, the Company plans to form strategic alliances with component manufacturers, systems assemblers, and service companies to provide power for consumers with units under lease or by sale. The service companies may be utilities. Other services or utility companies such as water, gas, telephone, cable, plumbing, and HVAC companies are also potential partners. The Company may have its plasma-electric power cell manufactured under contract or license. Alternatively, the Company may manufacture the units itself.

Table 3. Economics of International Fuel Cells Corp.

Basis: Installed Cost < $1,000/kW DOE Credit—$3,000 kW
Capital Recovery Factor—12%
Annual Load Factor—95% (8,322 hrs of operation)
Electric Efficiency (higher heating value)—36%
Heat Rate—9,480 Btu / kWh
Waste Heat Recovery as Hot Water
(Equivalent to 875,000 Btu/hr of fuel input at 80% efficiency)
Implicit Overall Thermal Efficiency—82%
Natural Gas Cost—$3.50 / million Btu

Cents/kWh	
Capital Charges	4.3
Fuel	3.3
O&M	2.0*
Subtotal	9.6
Hot Water Credit	-1.5
Net Power Cost	8.1

* Includes $600/kW overhaul costs every six years

Some of the competitive advantages of BlackLight Power generation over the competing microdistributed technologies fuel cells and micro combustion turbines are no fuel costs, no fuel handling issues nor pollution, not a heat engine and not electrochemical, no reformer, solid state device, chemically-generated plasma with proven microwave technology, linearly scalable, cost competitive (lower capital and O&M costs), long product lifetime, appliance-like, load following, no grid connection (gas or electric for fuel or load leveling), high 9's power capability, closed system, and valuable solid chemical by-product.

With strategic alliances, the Company plans to develop, manufacture, and market a unit of approximately twenty five kilowatt electric (25 kWe) which is a desirable size for a modular uninterruptable power supply for the premium power market. 25 kWe is also capable of providing for the total power requirements of a single family residence or a light commercial load. The potential advantages of the Company's power system compared to fuel cells are (1) zero fuel costs, (2) capital and O&M costs that are 10% that of fuel cells, and (3) valuable chemicals are produced rather than pollutants such as carbon dioxide. Thereby, the cost per kilowatt of electric generated by the Company's plasma-electric power cell is projected to be about 10% of that of a fuel cell. In addition, an energy consumer may also derive revenue by

selling power back onto the distribution system when the full capacity of the system is not required by such consumer.

The components required to produce a BlackLight power system such as a vacuum vessel and magnets are mass manufacturable. For implementation in the third world and acquisition of market share in the first world, the plasma-electric cell requires essentially no fuel and fuel distribution infrastructure, no regional or on-site pipelines, no utility connection (gas or electrical), no electric lines, and no specialized or centralized manufacturing expertise. In each category, competing technologies are at a competitive disadvantage which could prevent broad adoption even if they were viable based on logistics and costs.

Fuel cells are not cost competitive with BlackLight technology. The cost of electricity with a molten carbonate fuel cell which has a much lower capital cost compared to a proton exchange membrane fuel (PEM) is given in Table 3. The projected capital cost for a BlackLight 5—25 kW plasma-electric system is about \$25/kW based on Freis' projections for a Post converter [43] which is comparable to projections for a gyrotron system [6]. A mirror MHD system is projected to be less than that of a Post converter.

Also with strategic alliances, the Company further plans to develop, manufacture, and market a unit of approximately 1 MWe. One to ten of these units should provide the total power load requirements of a central power grid substation. The potential advantages of the Company's power system compared to central power are the same as with plasma-electric power cell. The cost per kilowatt of electric generated by the Company's plasma-electric power cell is projected to be about 20% of that of central power (see Table 2). With the installation of substation units, light commercial, and residential units, all components of the present central power generation infrastructure upstream from the substation may be eliminated. Some infrastructure components that may be eliminated by the Company's technology with associated cost savings are: (1) high voltage transformers, (2) high voltage transmission lines, and (3) central power plants, including their associated turbines, fuel and pollution handling systems, ash, pollution, coal trains, coal mines, gas pipelines, gas fields, super tankers, oil fields, nuclear power plants, uranium processing plants, and uranium mines.

5.4. Motive Power—Plasma-Electric and Battery

The capital cost for BlackLight power for motive power are comparable to the cost of an automotive internal combustion engine. Whereas, fuel cells are two orders of magnitude too expensive and require trillions of dollars to be invested in a hydrocarbon to hydrogen refueling system. In contrast, a motive power plant based on BlackLight technology uses water as the fuel and requires no infrastructure. The Company is considering several promising options to

commercialize its process in the motive power market. In addition to stationary power, the plasma-electric system may be used for motive power. The Company is also developing a high voltage battery which may power an electric vehicle.

5.6. Conclusion

The BlackLight Process has potentially very broad applications including: electrical power generation, space and process heating, motive power, and production of HHCs.

The technology generates plasma and heat from hydrogen, which may be obtained from ordinary water. The implications of this development could be significant. If the technology becomes proven, then the energy from this process could possibly be used to cleanly and cheaply meet the world's demand for thermal, chemical, and mechanical energy as well as electricity. Over time, it may be possible to replace or retrofit coal-fired, gas-fired, and oil-fired electric power plants. This would help to abate global warming and air and water pollution. Moreover, it may be possible to replace or retrofit some of the world's nuclear power plants. With BlackLight technology, an opportunity exists to dramatically reduce the complexity and the cost of the generation station, which includes fuel handling, thermal generation, thermal to electrical conversion, pollution abatement and spent fuel disposal or storage systems.

The Company is focusing on possible electrical and heating applications for its technology including a fit with a converter to make electricity. Electrical power generation with the Company's plasma-electric power technology may represent a major opportunity to use a microdistributed system to replace existing infrastructure at considerable savings in capital and generation costs. Residential/light commercial units, substation units, and a low voltage local distribution system could replace the central power based current system. Adaptation of the Company's technology is facilitated by the deregulation of the utility industry and the demand for autonomous microdistributed power in developing countries.

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